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Analysis of change in electric energy cost with using renewable energy sources in Gökceada, Turkey: An island example

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ABSTRACT

In this study, electric requirement of Gökceada, the biggest island of Turkey is analyzed that how can it be supplied with renewable energy sources. In order to consider the optimal system configuration of hybrid or non-hybrid renewable energy system, the HOMER program is used. At relevant studies which are done about renewable energy sources, it is seen that cost analysis are done according to annual average values. But in this study, HOMER program is used in order to make the system which is generated with computer, as real as possible. On the other studies, it is found out that various changes which are occurred in the year cannot be added to the system. With HOMER; the effect of values which vary by the time like electric load, wind speed and solar radiation, is considered and than the electric system are modelled. For each of these data, 8760 values are formed in HOMER. HOMER cannot model transient changes which is smaller than 1 h. However; it is expressed that, hourly data are sufficient in order to analyze the system like this. In this study; systems which are composed of solar panels, wind turbines and batteries, auxiliary tools are modelled with considered various scenarios. Grid connection or diesel generators for backup power are also modelled. Values of components which form the renewable system of Gökceada, are determined by the simulations. The excess energy which occurs when the energy source is bigger than the load, can be sold to the grid and so, the cost of energy can be reduced. According to the simulation results; it is seen that, energy costs of wind energy systems are lower for Gökceada. It is revealed that wind energy is advantageous in Gökceada especially with grid sales according to the grid connected scenario.

Contents

Abbreviations: TEIAS, Turkish electricity transmission company; EPDK, energy market regulatory authority; HOMER, hybrid optimization model for electric renewables; NREL, National Renewable Energy Laboratory; MV, medium voltage.

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1. Introduction

The energy is one of the most important factors which affects and forms our daily life. Basic life requirements like water and food are also obtained and transported by the energy. For this reason, having high quality and uninterruptable energy is a basic requirement.

Due to reasons like rising of fuel prices, energy needs, pollution and green house gasses, the use of environment friendly renewable energy sources are getting rapidly higher. Because of quite high renewable energy potential in our country, renewable energy systems are also getting popular.

In this study, electricity need of Gökceada which is the biggest island of Turkey is analyzed and renewable energy systems are used in this analysis. In order to determine the optimal renewable energy hybrid system design that can cover the load for Gökceada HOMER (hybrid optimization model for electric renewables) is used. HOMER is a computer model that is developed by NREL (National Renewable Energy Laboratory) and performs comparative economic analyses on proposed and actual distributed generation power systems. HOMER can also model systems that are not hybrids, like standalone PV systems. For a particular application scenario, inputs to HOMER include load data, renewable resource data, system component specifications and costs, and various information of optimization (e.g. number of components). Furthermore, HOMER can perform "sensitivity analyses" where the values of certain parameters (e.g. PV cell cost) can be varied to determine their impact on the COE (cost of energy) for the system in question. Further details of HOMER will be given when appropriate in the various sections on technology. To obtain the input data for HOMER, component information was collected from research literature and manufacturers to obtain estimates of costs.

To limit input complexity, and to permit fast enough computation to make optimization and sensitivity analysis practical, HOMER's simulation logic is less detailed than that of several other time-series simulation models for micropower systems, such as Hybrid2, PV-DesignPro, and PV*SOL. On the other hand, HOMER is more detailed than statistical models such as RETScreen, which do not perform time-series simulations. Of all these models, HOMER is the most flexible in terms of the diversity of systems it can simulate [1].

In the relevant studies which are done about renewable energy sources, it is seen that cost analysis are done according to annual average values. In this study, HOMER program is used in order to make the system model more realistic. On the other studies, it is found out that various changes which are occurred in the year cannot be added to the system. With HOMER; the effect of values which vary by the time like electric load, wind speed and solar radiation, to the electric system are modelled. For each of these data, 8760 values are formed in HOMER. HOMER cannot model transient changes which is smaller than 1 h. However; it is expressed that, hourly data is sufficient in order to analyze the systems like this type.

Before installing a renewable energy system, economical analysis should be made. HOMER makes economical analysis and ranks the systems according to their Net Present Costs. Net Present Cost Method is the reduction of costs and benefits of the system which will happen in the future to the present time. Although a system has more investment cost, it can be more economic according to its lifetime cost.

2. Description of Gökceada

2.1. Location and population

Gökceada is the biggest island of Turkey which is in the Northern Aegean Sea. Gökceada lies between 40°14′N to 40°05′N latitudes and 25°39′E to 26°00′E longitudes and its surface area is 285.5 km^2. Gökceada's population is about 8600 [2,3].

2.2. Load profiles of the island and electrification

Gökceada's electricity need is supplied from TEIAS's Kumlimanı Transformer Substation. This transmission line is 31.5 kV line.

HOMER simulates the operation of a system by making energy balance calculations for each of the 8760 h in a year. The hourly load profiles are not available for a whole year, so HOMER was used to synthesize the load profiles (with randomness) by entering the values for a typical day. For day-to-day randomness 5% is used and for time-step-to-time-step randomness 5% is used.

Gökceada's load profiles were obtained from TEIAS's Kumlimanı Transformer Substation. For winter profiles the data of the date 05.01.2007 is used and for summer profiles the data of the date 08.08.2007 is used. Load profile which is obtained by using values for winter is shown in Fig. 1 [4]. The minimum load demand occurs in winter between 01 and 08 o'clock. Load profile which is obtained by using values for summer is shown in Fig. 2. In summer, load demand is bigger, because Gökceada is a touristic island and population increases in summer. For summer, maximum value of load demand is 3000 kW which occurs on hours between 21:00 and 22:00.

2.3. Availability of renewable energy sources

2.3.1. Solar radiation

Gökceada's monthly solar radiation values are obtained with HOMER from NASA. For coordinates in HOMER, 40°11′N latitude and 25°54′E longitude are used. This is the coordinates of Centrum of Gökceada. HOMER syntheses solar radiation values for each 8760 h of the year by using Graham algorithm. This algorithm produces realistic hourly data, and it is easy to use because it requires only the

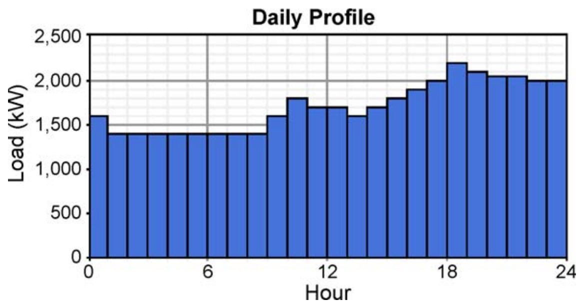

Fig. 1. Load profile for winter.

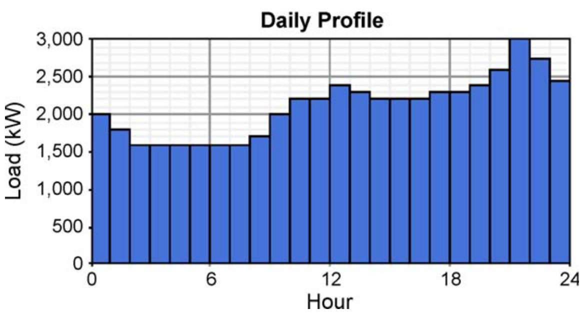

Fig. 2. Load profile for summer.

latitude and the monthly averages. The synthetic data displays realistic day-to-day and hour-to-hour patterns. If one hour is cloudy, there is a relatively high likelihood that the next hour will also be cloudy. Similarly, one cloudy day is likely to be followed by another cloudy day. The synthetic data is created with certain statistical properties that reflect global averages. So data generated for a particular location will not perfectly replicate the characteristics of the real solar resource. But tests show that synthetic solar data produce virtually the same simulation results as real data [5]. Monthly average values of solar data are shown in Fig. 3.

2.3.2. Wind speeds

Gökceada is one of the windiest regions of Turkey. In this study, wind speed data of Aydıncık site of the island are used.

In HOMER, wind speed data are extrapolated by using the following power–law formula:

$$\frac{V(z)}{V(z_r)} = \left(\frac{z}{z_r}\right)^{\alpha} \quad (1)$$

where $V(z)$ is wind speed estimated at desired height z, $V(z_r)$ is wind speed at boundary layer height z_r and α is the power–law index. For Gökceada's Aydıncık region, α is used as 0.19. This value also includes surface roughness effect, because 0.19 had been found by making measurements with anemometers at 10 and 30 m by using Eq. (1) [6].

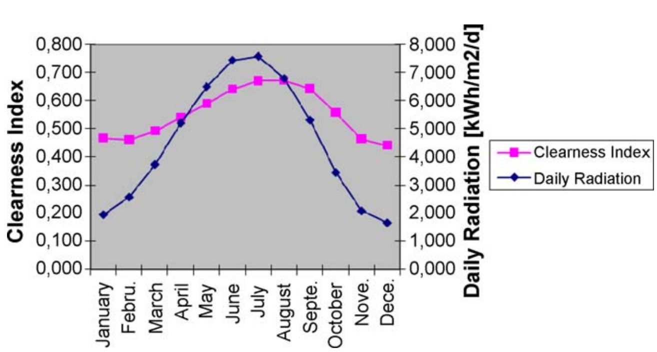

Fig. 3. Average solar radiation data for Gökceada.

In order to calculate the power of a WT, we must have knowledge of the wind speeds. When hourly wind speed measurements are not available, hourly data can be generated synthetically from monthly averages. HOMER's synthetic wind data generator is a little more difficult to use than the solar data generator because it requires four parameters:

The Weibull k value (k) is a measure of the distribution of wind speeds over the year. It is 2 by default because this has been shown to represent most wind regimes fairly accurately. Lower k values correspond to broader wind speed distributions, meaning that the wind speeds vary over a wide range. Wind regimes where the wind tends to vary over a narrower range (like tropical trade wind environments) have higher k values. 1.94 is used for k value in this study. 1.94 is the average of annual Weibull k values which is measured at Aydıncık site [7].

The autocorrelation factor (r_1) is a measure of the randomness of the wind. Higher values indicate that the wind speed in one hour tends to depend strongly on the wind speed in the previous hour. Lower values indicate that the wind speed tends to fluctuate in a more random fashion from hour-to-hour. This parameter is influenced by local topography. Autocorrelation factors tend to be lower (0.70–0.80) in areas of complex topography and higher (0.90–0.97) in areas of more uniform topography. In this study, 0.8 is used.

The diurnal pattern strength (δ) is a measure of how strongly the wind speed depends on the time of day. In most locations, for example, the afternoon tends to be windier than the morning. Higher values indicate that there is a relatively strong dependence on the time of day. Lower values indicate that the wind speed is not strongly related to the time of day. In this study, 0.3 is used.

The hour of peak wind speed is simply the time of day that tends to be windiest on average throughout the year.

In this study, 11:00 is used as the hour of peak wind speed [7].

The monthly wind speed averages for Gökceada have been extracted from Ref. [6]. These values are of 50 m height. For this reason, anemometer height in HOMER simulations will be 50 m. The monthly wind speed averages at Ref. [6] are shown in Fig. 4. Probability distribution function of wind speed data synthesized by HOMER is shown in Fig. 5. In Fig. 6, the map of Gökceada island indicating locations of the stations is shown.

3. PV and wind energy systems

3.1. PV system

A solar cell is a semiconductor device designed to turn solar irradiance into electricity. If solar cells are connected in series, then

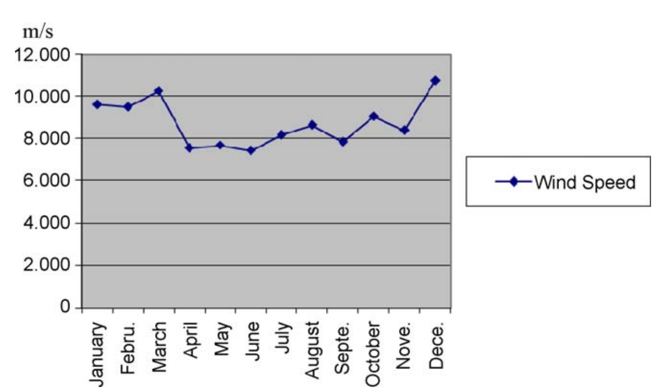

Fig. 4. Average wind speeds in Aydıncık (m/s) [6].

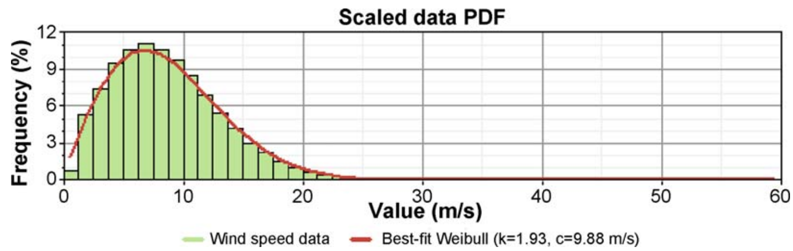

Fig. 5. Probability distribution function of wind speed data synthesized by HOMER.

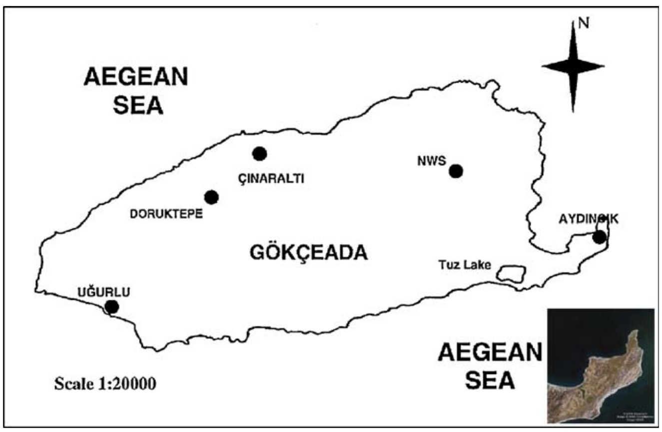

Fig. 6. Map of Gökceada Island indicating locations of the stations [6].

the current stays the same and the voltage increases. If solar cells are connected in parallel, the voltage stays the same, but the current increases. Solar cells are combined to form a module to obtain the voltage and current (and therefore the power) desired. A PV array is a group of PV modules put together to generate electricity. A PV array produces DC voltage and current those are used to power the load.

HOMER always deals with the PV array in terms of rated kW, not in m^2. So it does not need to know the efficiency. By the way, HOMER assumes that the output of the PV array is linearly proportional to the incident radiation, so if the radiation is 0.75 kW/m^2, the array will produce 75% of its rated output.

PV panels become less efficient as their temperature increase. The power produced is roughly anti-linear in the temperature range under which PV panels are exposed. Manufacturers assign a value to this characteristic, and it is usually expressed as a percentage change of the total power per °C. For example, if a panel has a temperature coefficient of power that is −0.50%/°C, the panel produces 0.5% less power for every 1 °C increase in temperature. PV panels are exposed to sunlight, they absorb the infrared radiation produced by the sun and they heat up. Moreover, they are dark coloured and tend to warm significantly: as hot as 80 °C when there is no wind blowing. It is worth noting that HOMER's PV input page has a debating factor. This is used to compensate for the reduction in efficiency because real world conditions are somewhat less favourable than standard test conditions. The most important factor is array temperature, but dust and wiring losses have a small effect also. The default value is 90%. A slightly lower number should be used in very hot climates [8].

To account for these loses and these due to soiling of the PV panels, we enter a debating factor that is a scaling factor applied to the PV array output and for Gökceada, debating factor is assumed as 90%.

The energy produced by the PV array is calculated using the following formula:

$$P_{PV} = f_{PV} \cdot Y_{PV} \cdot \left(\frac{I_T}{I_s}\right) \tag{2}$$

where f_{PV} is the debating factor, Y_{PV} is the total installed capacity of the PV array, I_T is the solar radiation and I_s = 1 kW/m^2 [5].

3.2. Wind energy system

In the simulations, GE 1.5sl type wind turbine is used because this wind turbine is one of the turbines which are used in Turkey and also in HOMER's database. Parts of the GE 1.5sl wind turbine are heat exchanger, control panel, generator, oil cooler, coupling, hydraulic parking brake, main frame, impact noise insulation, gearbox, yaw drive, rotor shaft, bearing housing, rotor hub, pitch drive, nose cone, ventilation and nacelle (Fig. 7).

Technical Data of GE 1.5sl Wind Turbine

Rated capacity	1500 kW
Cut-in wind speed	3.5 m/s
Cut-out wind speed	20 m/s
Rated wind speed	14 m/s
Number of rotor blades	3
Rotor diameter	77 m
Swept area	4657 m^2
Rotor speed (variable)	11.0–20.4 rpm
Power control	Active blade pitch control
Hub heights	61.4–100 m (80 m is used for simulations)

4. Economic analysis

4.1. Annual real interest rate

The annual real interest rate is one of the HOMER's input which is also called the real interest rate or just interest rate. It is the discount rate used to convert between one-time costs and annualized costs. It is found in the *Economic Inputs* window. The annual real interest rate is related to the nominal interest rate by the equation given below:

$$i = \frac{i' - f}{1 + f} \tag{3}$$

In this equation, i is the real interest rate, i' is the nominal interest rate (the rate at which you could get a loan), and f is the annual inflation rate.

For Turkey, i' = 15.25% (18.02.2008) and f = 8.4% (year 2007 annual inflation rate) are used. With these values, according to Eq. (3) real interest rate is found 6.3% as shown below [10,11]:

$$i = \frac{i' - f}{1 + f} = \frac{0.1525 - 0.084}{1 + 0.084} = 0.063$$

In HOMER simulations, 6.3% is used for real interest rate.

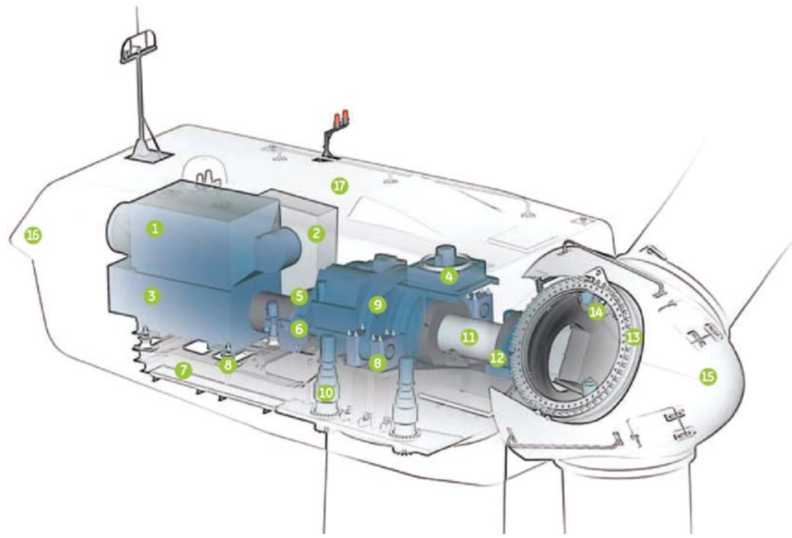

Fig. 7. GE 1.5sl Wind Turbine which is used in the simulations of this study [9].

4.2. Levelized cost of energy

HOMER defines the levelized cost of energy (COE) as the average cost/kWh of useful electrical energy produced by the system. To calculate the COE, HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production. The equation for the COE is as follows:

$$\mathrm{CoE} = \frac{C_{ann,tot}}{E_{prim,AC} + E_{prim,DC} + E_{grid,sales}} \tag{4}$$

In this equation: $C_{ann,tot}$ is total annualized cost [$/year], $E_{prim,AC}$ is AC primary load served [kWh/year], $E_{prim,DC}$ is DC primary load served [kWh/year], $E_{grid,sales}$ is total grid sales [kWh/year].

The total annualized cost is the sum of the annualized costs of each system component, plus the other annualized cost. It is an important value because HOMER uses it to calculate both the levelized cost of energy and the total net present cost [5].

4.3. Net present cost (NPC)

The present value of the cost of installing and operating the system over the lifetime of the project (also referred to as lifecycle cost). Project lifetime in this study is considered as 20 years.

The total net present cost is HOMER's main economic output. All systems are ranked according to net present cost, and all other economic outputs are calculated for the purpose of finding the net present cost. The net present cost is calculated according to the following equation [5]:

$$C_{\mathrm{NPC}} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{5}$$

In this equation $C_{ann,tot}$ is total annualized cost [$/year], CRF is capital recovery factor, i = real interest rate [%], R_{proj} is project lifetime [year] (20 years in this study).

The capital recovery factor is a ratio used to calculate the present value of an annuity (a series of equal annual cash flows). The equation for the capital recovery factor is

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N - 1} \tag{6}$$

where i is real interest rate [%] and N is number of years.

5. The scenarios considered for Gökceada

In this chapter, some scenarios will be considered in order to supply the electricity need of Gökceada with different energy sources. For every scenario, total net present cost and levelized cost of energy will be found. Values which are shown in Table 1 will be used for money transforms and fuel prices in this report. These values are taken on the date 04.04.2008 [11–13].

The system costs which are given in Table 2 will be used for HOMER simulations. Personnel outgoings, transport cost, ground rent or price, tax and other cost are neglected in the simulations. 10$ will be used for annual operating and maintenance costs of PV modules, batteries and converters in simulations [14,15]. Although, in ideal working conditions; PV panels, batteries, inverters and charge regulators are inexpensive. Operating and maintenance costs are indefinite in real working condition.

Wind turbine capital cost is considered as 1000 $/kW [16]. For every kW of PV modules, capital cost is assumed as 7000$. Hoppecke 20 OPzS 2500 (2500 Ah) batteries are chosen in HOMER simulations. For every battery, 1500$ is suggested as capital cost. Converters' capital cost is assumed as 1000$ for 1 kW. Converter cost includes inverter, rectifier and charge controller cost. Diesel generators' capital cost is assumed as 200$ for 1 kW.

5.1. Wind stand alone system

In this scenario, Gökceada's entire load is supplied with wind energy. HOMER model of the system is given in Fig. 8. Wind speed is not enough for all time, so batteries and converters are needed for backup power. Adding batteries also increases the cost of the system; but by this way all energy requirements can be supplied with renewable energy and renewable fraction will be 100%.

The rated power of GE 1.sl type wind turbine is 1.5 MW. Capital cost of the turbine is considered as 1500×1000 = 1,500,000$. For every kW of the rated power, 1000$ is used [16]. For operating and maintenance cost 30,000$ is used (2% of capital cost). 7 wind turbines are found for optimal operation. In this case, monthly average electric production is shown in Fig. 9. 9500 number of

Table 1
Used values for simulations.

$ (TL)	€ (TL)	Diesel (TL/L)	Diesel ($/L)
1.290	2.027	2.89	2.24

Table 2
System cost values that used in simulations.

		Capital cost ($)	Replacement cost ($)	Operating and maintenance cost ($/year)
Wind turbines	1 kW	1000	1000	2% of Capital cost
PV modules	1 kW	7000	7000	10
Batteries	1 num.	1500	1500	10
Converters (Inverter + rectifier + charge controller)	1 kW	1000	1000	10
Diesel generators	1 kW	200	160	3 ($/hour)

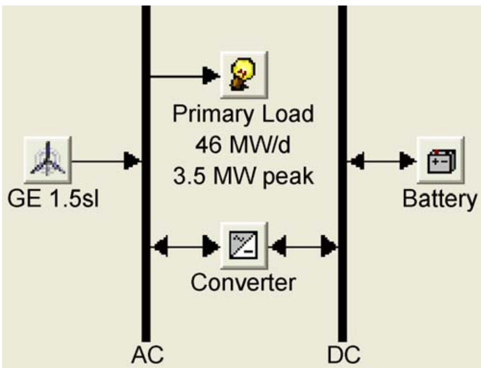

Fig. 8. HOMER model of the system.

batteries and 3500 kW converter power are needed according to simulation. With these values, NPC of the system is found as 32,537,056$ and 0.174 $/kWh is the cost of energy. As it is seen in Table 3 battery cost is the biggest value of the cost breakdown. The excess electrical production is shown in Fig. 10. In real world, excess electrical production should not occur due to the control system of the wind turbine. But, simulations show that excess electrical energy occurs and this energy can be sold by grid connection. The simulation results are given below:

System architecture	
Wind turbine	7 GE 1.5sl
Battery	9,500 Hoppecke 20 OPzS 2500
Inverter	3,500 kW
Rectifier	3,500 kW
Cost summary	
Total net present cost	32,537,056$
Levelized cost of energy	0.174 $/kWh

5.2. PV stand alone system

In this scenario, Gökceada's entire load is supplied with solar energy. HOMER model of the system is given in Fig. 11. NPC of the system is found as 223,835,376$ and 1200 $/kWh is the cost of energy. As it is seen in Table 4, PV array cost is the biggest value of the cost breakdown. In this case, monthly average electric production is shown in Fig. 12. The excess electrical production occurs as shown in Fig. 11. In real world, excess electrical production should be eliminated by using dump loads. Also, excess electrical energy can be eliminated with grid sales (Fig. 13).

HOMER simulation results are given as follows:

System architecture	
PV array	25,000 kW
Battery	32,750 Hoppecke 20 OPzS 2500
Inverter	3,200 kW
Rectifier	3,200 kW
Cost summary	
Total net present cost	223,835,376$
Levelized cost of energy	1.200 $/kWh

5.3. WT–PV hybrid system

In this scenario, Gökceada's load is supplied with wind and solar energy together. HOMER model of the investigated system is given in Fig. 14. In this case, monthly average electric production and the excess electrical production are shown in Figs. 15 and 16, respectively. NPC of the system is found as 34,014,936$ and 0.182 $/kWh is the cost of energy.

HOMER simulation results are given as follows:

System architecture	
PV array	500 kW
Wind turbine	6 GE 1.5sl
Battery	10,000 Hoppecke 20 OPzS 2500
Inverter	3,000 kW
Rectifier	3,000 kW
Cost summary	
Total net present cost	34,014,936$
Levelized cost of energy	0.182 $/kWh

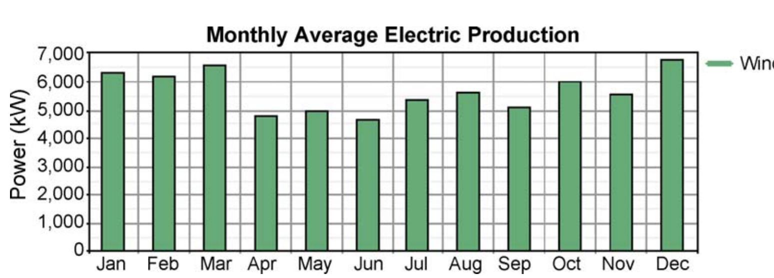

Fig. 9. Monthly average electric production.

Table 3
Cost breakdown.

Component	Initial capital ($)	Annualized capital ($/year)	Annualized replacement ($/year)	Annual O&M ($/year)	Annual fuel ($/year)	Total annualized ($/year)
GE 1.5sl	10,500,000	937,858	0	210,000	0	1,147,858
Battery	14,250,000	1,272,807	42,919	95,000	0	1,410,726
Converter	3,500,000	312,619	0	35,000	0	347,619
Total	28,250,000	2,523,284	42,919	340,000	0	2,906,203

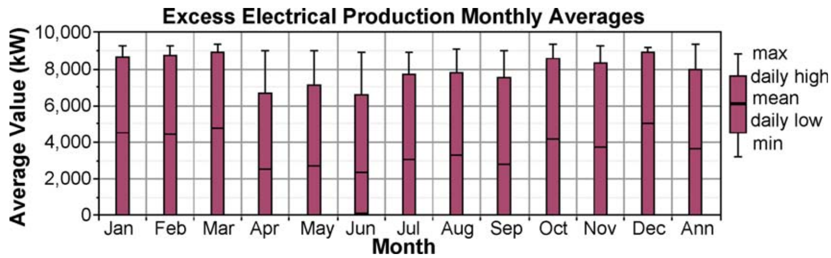

Fig. 10. Excess electrical production monthly averages.

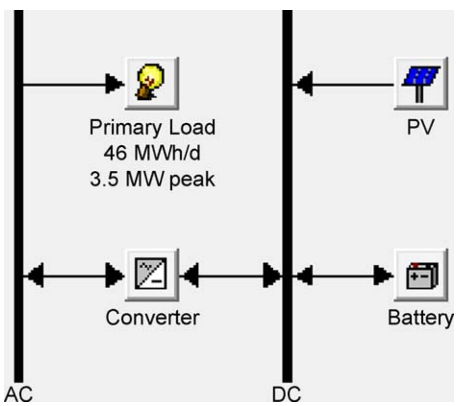

Fig. 11. HOMER model of the system.

5.4. Diesel generator system

In this scenario, Gökceada's entire load is supplied with diesel generators. Optimal generator power is found as 3300 kW with HOMER.

By using values from Table 5, for 20 year of project lifetime NPC is found as 144,437,248$. Levelized cost of energy is found as 0.774 $/kWh. Annual fuel consumption is 5,403,237 L/year and annual fuel consumption cost is 12,103,250 $/year as shown in Table 6. Specific fuel consumption is 0.324 L/kWh and average electrical efficiency is 31.4%. Carbon dioxide emission is 14,228,501 kg/year and sum of the other GHG gas emissions is 383,620 kg/year according to Table 7. Monthly average electric production and diesel generator electrical output monthly averages are given in Figs. 17 and 18, respectively (Table 6).

HOMER simulation results are given below:

System architecture	
Generator 1	3,300 kW
Cost summary	
Total net present cost	144,437,248$
Levelized cost of energy	0.774 $/kWh

Table 4
Cost breakdown.

Component	Initial capital ($)	Annualized capital ($/year)	Annualized replacement ($/year)	Annual O&M ($/year)	Annual fuel ($/year)	Total annualized ($/year)
PV array	175,000,000	15,630,963	−921,193	250,000	0	14,959,770
Battery	49,125,000	4,387,835	0	327,500	0	4,715,335
Converter	3,200,000	285,823	0	32,000	0	317,823
Total	227,324,992	20,304,620	−921,193	609,500	0	19,992,928

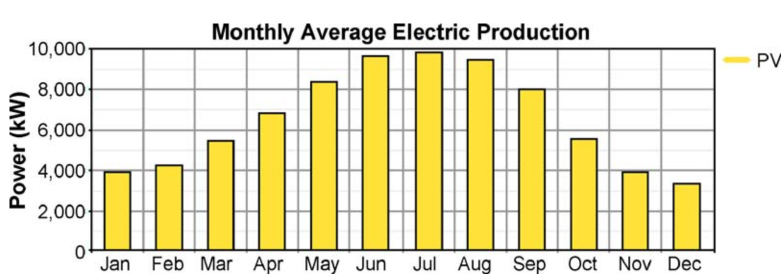

Fig. 12. Monthly average electric production.

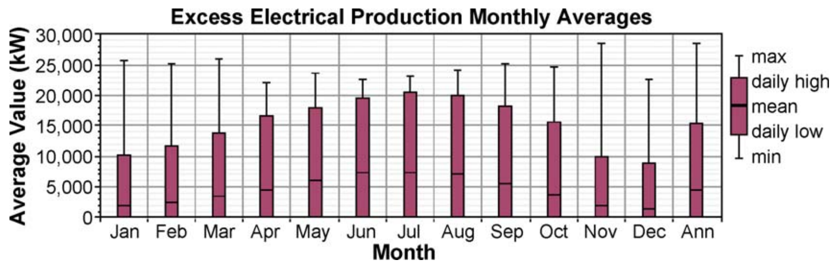

Fig. 13. Excess electrical production monthly averages.

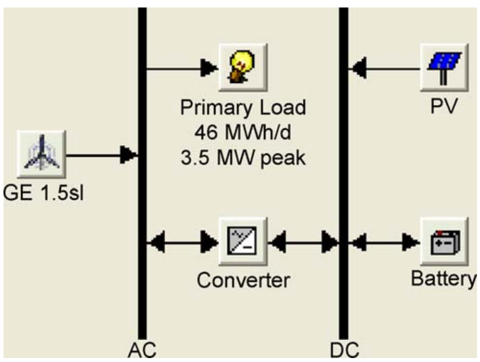

Fig. 14. HOMER model of the system.

5.5. WT grid-connected

In this scenario, Gökceada's load is supplied with wind energy system connected to the grid. HOMER model of the investigated system is given in Fig. 19. In this case, if wind speed is not enough to supply the Gökceada's load, the needed energy is supplied with purchasing energy from the grid. Otherwise, if the energy produced by wind turbines excesses the energy demand of Gökceada, the excess electrical energy production is sold to the grid.

5.6. PV grid-connected

In this scenario, Gökceada's load is supplied with solar energy system connected to the grid. HOMER model of the investigated system is given in Fig. 20. In this case, if solar energy is not enough to supply the Gökceada's load the needed energy is supplied with purchasing energy from the grid. Otherwise, if the energy produced by PV arrays excesses the energy demand of Gökceada, the excess electrical energy production is sold to the grid. In the investigated case, because more energy is sold to the grid the converter capacity is expanded. The most suitable value for energy cost is obtained as 28,000 kW for the converter capacity.

5.7. WT–PV grid-connected

In this scenario, Gökceada's load is supplied with wind and solar energy systems connected to the grid through synchronization mechanism. HOMER model of the investigated system is given in Fig. 21. In this case, if the energy produced with the renewable energy systems investigated is not enough to supply the Gökceada's load, the needed energy is supplied with purchasing energy from the grid. The cost of energy for all of scenarios are given in Fig. 22.

5.8. Results of scenarios

Simulation results are given in Table 8. According to scenarios, the most economic system is found as wind turbine system. For standalone WT system, cost of energy is 0.174 $/kWh and excess electricity is 31,833,954 kWh/year which is 64.2% of total electrical production. If the system is grid connected, the excess electricity can be sold to the grid. By this way, energy cost of the wind turbine system is dropped to 2$ Cents. This cost is found for 7 wind

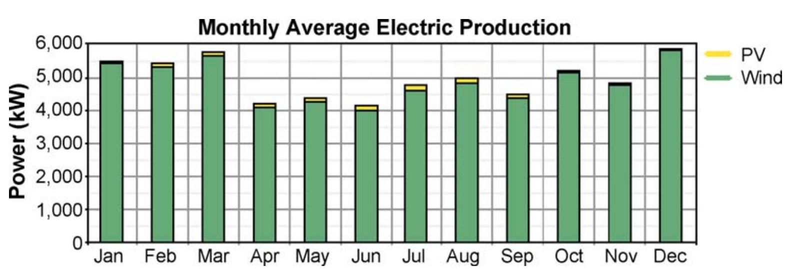

Fig. 15. Monthly average electric production.

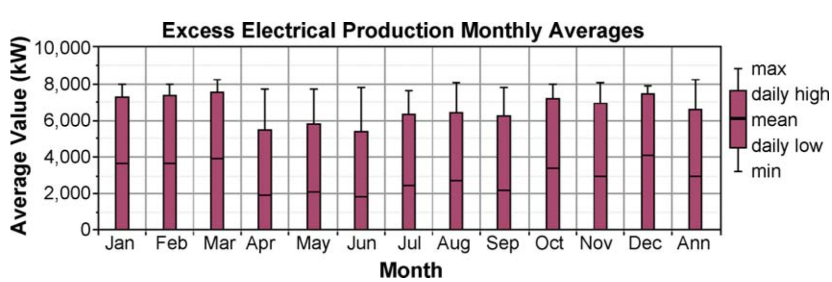

Fig. 16. Excess electrical production monthly averages.

Table 5
Cost breakdown.

Component	Initial capital ($)	Annualized capital ($/year)	Annualized replacement ($/year)	Annual O&M ($/year)	Annual fuel ($/year)	Total annualized ($/year)
PV array	3,500,000	312,619	−18,424	5,000	0	299,195
GE 1.5sl	9,000,000	803,878	0	180,000	0	983,878
Battery	15,000,000	1,339,797	17,377	100,000	0	1,457,174
Converter	3,000,000	267,959	0	30,000	0	297,959
Total	30,500,000	2,724,254	−1,047	315,000	0	3,038,207

Table 6
Cost breakdown.

Component	Initial capital ($)	Annualized capital ($/year)	Annualized replacement ($/year)	Annual O&M ($/year)	Annual fuel ($/year)	Total annualized ($/year)
Generator 1	660,000	58,951	160,743	578,160	12,103,250	12,901,104
Total	660,000	58,951	160,743	578,160	12,103,250	12,901,104

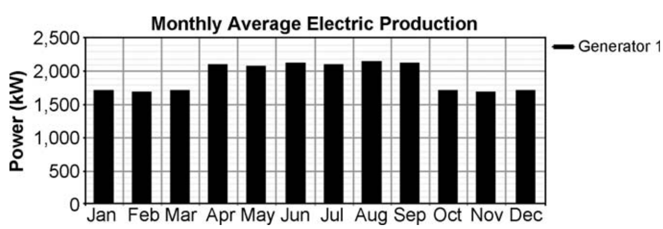

Fig. 17. Monthly average electric production.

Table 7
Gas emissions.

Pollutant	Emissions (kg/year)
Carbon dioxide	14,228,501
Carbon monoxide	35,121
Unburned hydrocarbons	3,890
Particulate matter	2,648
Sulphur dioxide	28,573
Nitrogen oxides	313,388

turbines. If the number of wind turbines is increased, cost of energy decreases with increasing grid sales. When the WT system is connected to grid, in other words, when battery and converter are not used for backup power, as 9500 battery units and 3500 kW converter are not exist, cost of energy is much more reduced. The COE is found as −0.083 $/kWh as shown in 6th row of Table 9. In this case, due to purchasing incomes are higher than the total costs, NPC and COE have negative values.

According to renewable energy law, EPDK (Energy Market Regulatory Authority) of Turkey is determined price of electric as 9.67 kr/kWh for end of 2007. 9.67 kr/kWh is 4.78 €cent/kWh. According to EPDK, selling price should not be less than 5 €cent/kWh. For selling price, 5 €cent/kWh (7.86 $Cent/kWh) is used. For buying price, 7.86 $Cent/kWh + Tax = 9.28 $Cent/kWh is used [17].

At PV–WT hybrid system, it is seen that installing PV panels is not economic. Also, diesel generator is more economic than PV system.

In Table 9, some additional simulation results are given. Battery cost is very effective on NPC and COE because of the high battery prices. If batteries are not used for backup power, costs of renewable energy systems are reduced. For instance, if back up energy is supplied from the grid for WT scenario, NPC and COE of the system go to negative. Because incomes with grid sales become greater than the costs, NPC of the grid connected WT system is −15,505,178$ and COE is −0.083 $/kWh.

5.9. Area need for renewable systems

Area need for renewable systems are suggested according to scenarios which have the largest amounts. For instance, area need for PV arrays is calculated by using the amount of PV array size of PV standalone system scenario. Area needed for diesel generators and converters are ignored because their dimensions are small compared to the other systems.

5.9.1. Area need for wind turbines

According to simulations at most 7 wind turbines are needed. These wind turbines are considered to install to Aydıncık site of the island. When placing the turbines, some criteria should be considered. Wind turbines should be aligned about 8–12 rotor

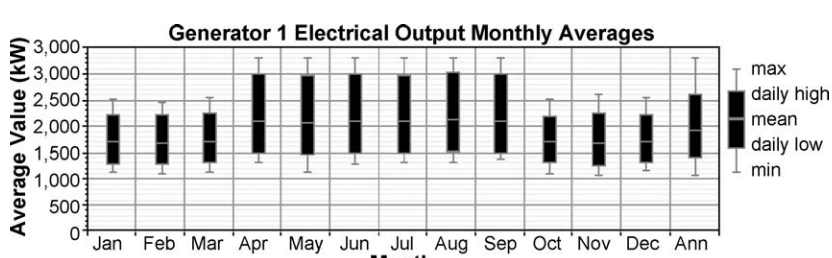

Fig. 18. Diesel generator electrical output monthly averages.

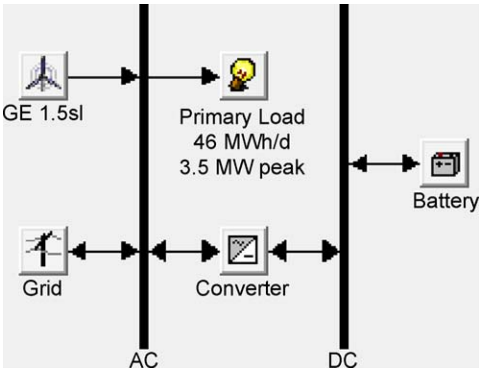

Fig. 19. HOMER model of the system.

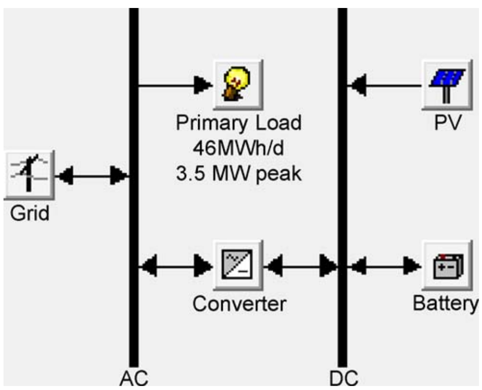

Fig. 20. HOMER model of the system.

diameter away from each other at prevailing wind direction. For vertical arrangement to the wind direction, wind turbines should be placed with a distance of 2–4 rotor diameters. If the turbines are installed by two rows $(3 + 2) \times (3 \times 80) \times (8 \times 80)/2 = 384{,}000\ m^2$ area is needed (Rotor diameter is supposed to be 80 m.). Aydıncık site has about 8,000,000 m^2 area and this is enough for wind turbines. In Fig. 23 wind turbine layout is shown. Prevailing wind direction is considered as North-East because of northeast wind (boreas) [3,18].

5.9.2. Area need for PV arrays

For standalone PV system scenario 25,000 kW PV arrays are needed. If 7.5 m^2 is used for 1 kW PV module, then total area need is $7.5 \times 25{,}000 = 187{,}500\ m^2$ [19].

For PV arrays, use of Aydıncık section is not imperative. To supply the load closer is better to avoid the voltage drop and transmission losses.

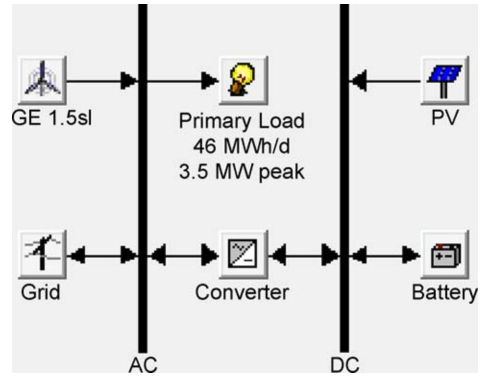

Fig. 21. HOMER model of the system.

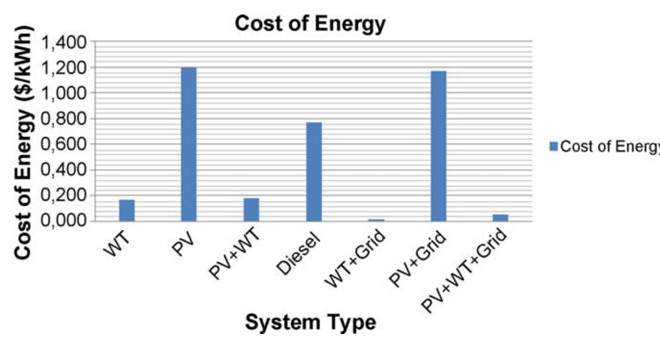

Fig. 22. Cost of energy results of simulations.

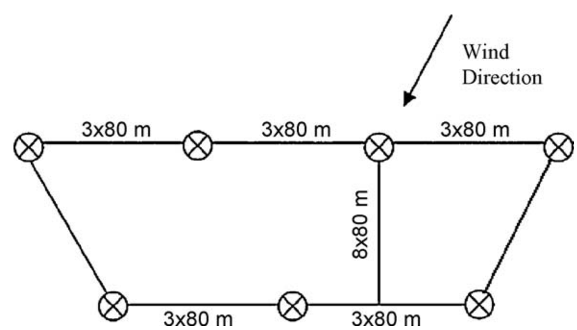

Fig. 23. Wind turbine layout.

5.9.3. Area need for batteries

For standalone PV system scenario number of batteries is 32,750. Dimensions of 20 OPzS 2500 battery are $0.215\ m \times 0.49\ m \times 0.815\ m$. Then area requirement of batteries is found as $0.215 \times 0.49 \times 32{,}750 = 3450\ m^2$ [20].

Table 8
Simulation results.

	System type	WT (number)	PV (kW)	Diesel generator (kW)	Battery (number)	Converter (kW)	Total net present cost ($)	Cost of energy ($/kWh)	Renewable fraction (%)
1	WT	7	–	–	9,500	3,500	32,537,056	**0.174**	100
2	PV	–	25,000	–	32,750	3,200	223,835,376	1.200	100
3	PV + WT	6	500	–	10,000	3,000	34,014,936	0.182	100
4	Diesel	–	–	3300	–	–	144,860,688	0.774	0
5	WT + Grid	7	–	–	9,500	3,500	3,700,266	**0.020**	93
6	PV + Grid	–	25,000	–	32,750	28,000	219,393,472	1.175	87
7	PV + WT + Grid	6	500	–	10,000	3,000	10,880,557	0.058	92

Table 9
Detailed simulation results.

	System type	WT (number)	PV (kW)	Diesel generator (kW)	Battery (number)	Converter (kW)	Total net present cost ($)	Cost of energy ($/kWh)	Renewable fraction (%)
1	WT	7	–	–	9,500	3500	32,537,056	**0.174**	100
2	PV	–	25,000	–	32,750	3200	223,835,376	1.200	100
3	PV + WT	6	500	–	10,000	3000	34,014,936	0.182	100
4	Diesel	–	–	3300	–	–	144,860,688	0.774	0
5	Diesel	–	–	2400	700	700	132,389,160	0.710	0
6	WT + Grid	7	–	–	–	–	−15,505,178	**−0.083**	93
7	WT + Grid	7	–	–	9,500	3500	3,700,266	**0.020**	93
8	PV + Grid	–	25,000	–	–	28000	166,601,872	0.892	87
9	PV + Grid	–	25,000	–	32,750	28000	219,393,472	1.175	87
10	PV + WT + Grid	6	500	–	–	3000	−5,239,017	−0.028	92
11	PV + WT + Grid	6	500	–	10,000	3000	10,880,557	0.058	92
12	WT + Diesel	6	–	1000	10,000	3000	31,772,346	**0.170**	99,9
13	WT + Diesel	9	–	3000	–	–	56,695,876	0.304	94
14	PV + Diesel	–	2,000	2400	1,300	2500	117,928,472	0.632	**27**
15	PV + Diesel	–	2,000	3300	–	2000	139,138,208	0.745	**26**
16	PV + WT + Diesel	9	500	3000	–	600	59,420,276	0.318	94
17	PV + WT + Diesel	5	500	1000	10,000	3000	33,622,760	0.180	100

6. Conclusion and discussion

In this study, electricity need of Gökceada is analyzed and renewable energy systems are used in this analysis. In order to determine the optimal renewable energy hybrid system design that can cover the load for Gökceada HOMER software is used. HOMER is a computer model that is developed by NREL (National Renewable Energy Laboratory) and performs comparative economic analyses on proposed and actual distributed generation power systems.

In this study we tried to analyze some studies made for responding a region's energy needs through choosing Gökceada, the biggest island of Turkey in the Aegean Sea.

Reasons for choosing Gökceada are those:

Gökceada is one of the most important regions of Turkey according to wind potential.

For it is an island, Gökceada's energy need is met by single energy transmission line. This situation is risky for continuity and reliability of energy. Because of an error in the transmission line, the whole island can be run out of electricity. Producing electricity in alternative ways in island may increase the continuity of electric energy and reliability.

The wind speed data taken from older studies about Gökceada are in suitable condition for using with HOMER programme.

In spite of having wind energy plant in the other island, Bozcaada, which has highly wind potential too, yet there is no wind energy plant in Gökceada.

For deciding renewable and most suitable hybrid or non-hybrid system to meet energy needs of Gökceada, computer software HOMER was used. To have input data of HOMER, it is tried to have information about the system which is used. These data were technical specifications, account and maintenance rates of system parts.

In this study, computer comparisons were made upon using renewable energy sources as sun and/or wind for 20 years lifetime. Beside this, it was thought to use diesel generators if necessary. Additionally the gas emissions were given, if diesel generator is used.

In conclusion, according to the simulation results; it is seen that energy costs of wind energy systems are lower for Gökceada. COE is about 17 $Cents. It is revealed that wind energy is advantageous in Gökceada especially with grid sales. With sales, COE decreases to 2 $Cents. And also, the Net Present Cost is much more reduced by using grid connection, instead of using batteries for backup power. To supply the need of electricity with wind energy would be a suitable investment for Gökceada. According to the results, approximately 384,000 m^2 area is needed to place the wind turbines and Gökceada has adequate land for such an implementation. PV systems have not been economic yet because of very high PV module and battery costs.

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References

[1] Farret, Felix A. Integration of alternative sources of energy. Wiley-Interscience; 2006.
[2] Google Earth™.
[3] Quide of Gökceada, http://www.gokceadarehberi.com.
[4] Turkish Electricity. Transmission Company, 2008 www.teias.gov.tr/eng/.
[5] HOMER Help files.
[6] Artar, H, Investigation of wind energy potential and energy transformation analysis of Gökceada, MSc Thesis, I.T.U. Institute of Science and Technology, Istanbul, 2005.
[7] Eskin N, Artar H, Tolun S. Wind energy potential of Gökceada Island in Turkey. Renewable and Sustainable Energy Reviews 2008;12(3):839–51.
[8] Camerlynck J. Modelling of renewable energy systems in the Maldives. Utrecht University; 2004.
[9] GE Energy, online tools, http://www.gepower.com/; 2008.
[10] Forex Brokerage Firms, http://www.fxstreet.com/fundamental/interest-rates-table; 2008.
[11] Central Bank of the Republic of Turkey, http://www.tcmb.gov.tr/; 2008.
[12] Bigpara Finance Portal, http://www.bigpara.com.
[13] Petrol Ofisi, Local Oil Prices in Turkey, http://gm.poas.com.tr/pompafiyat; 2008.
[14] Givler T, Lilienthal P, Explore the role of gensets in small solar power systems. NREL, US, http://www.nrel.gov/docs/fy05osti/36774.pdf; 2005.
[15] Dalton GJ, Lockington DA, Baldock TE. Feasibility analysis of stand-alone renewable energy supply options for a large hotel. Renewable Energy 2008;33(7):1475–90.
[16] Danish Wind Industry Association, http://www.windpower.org; 2008.
[17] Energy Market Regulatory Authority in Turkey, www.epdk.gov.tr; 2008.
[18] Patel MR. Wind and solar power systems: design, analysis, and operation. Boca Raton: Taylor & Francis; 2006.
[19] Sharp Electronics http://www.sharp-world.com.
[20] Mutlu Batteries and Tools http://www.mutlu.com.tr/.